CEMENT
AND
CEMENT MANUFACTURE

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The Chemistry of Cement

AN opportune time has been chosen for the publication of a new book* on cement chemistry, because the research work of recent years has led to theories concerning the constitution of Portland cement which are more generally accepted than any that have been advanced in the past. The solid solution theory can be abandoned, and there is no longer any need to refer to Alite, Belite, Celite, and Felite, because the principal components of clinker can be expressed in proper chemical terms of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetra-calcium-alumino-ferrite. From this starting point it is possible to investigate the respective contributions of these compounds to the strength and stability of Portland cement. It is true that the value of magnesia and alkalis in cement is still undetermined and it is not safe to assume that they act merely as fluxes, but the further necessary investigation of the minor components of cement will be largely a matter of spade work now that the framework of the structure is known.

The recently published work of one of the authors† may well be a landmark in the progress of the research on the constitution of commercial cement clinkers. This work is fully dealt with in the book, and it is evident that the glassy component of clinker will become the subject of not only research but of practical experiment. This component has the advantage of providing a liquid medium which facilitates combination of lime with silica during the burning operation, but whether it has any value as a strength-forming material in cement is not established, nor is it known whether the cooling of clinker should be arranged to induce crystallisation of the glass in order to secure the best results. These unanswered questions indicate that finality is not reached in connection with the

* The Chemistry of Cement and Concrete, by F. M. Lea and C. H. Desch. London: Edward Arnold & Co. Pp. xii + 429. Price 25s. net.

† "The Application of Phase Equilibrium Studies on the System CaO-Al_2O_3-SiO_2-Fe_2O_3 to Cement Technology," by F. M. Lea, *Cement and Cement Manufacture*, February, 1935.

ideal composition of cement, and it may even be that the manufacturing process can be modified with advantage to quality.

The chemistry of the setting and hardening of cement is the subject of divided opinions. The crystalline theory of setting still has its supporters, although they are apparently a minority compared with the advocates of the gel theory. It is, however, admittedly difficult to conceive that the high strengths attained by test pieces and by mass concrete are solely the result of gel cohesion. In another direction the technology of cement is still undecided, because the mortar tensile test with the minimum addition of water for plasticity which has hitherto been accepted as a standard is now stated to be misleading and a test with higher water-cement-ratio is preferred. Also, the maximum (molecular) lime ratio of three times silica and alumina which has been the basis of many formulæ is shown to be not in accordance with a theory worked out and submitted by the authors as established.

The authors' approach to the subject is essentially from the laboratory standpoint, and this explains why some of the statements will not obtain the concurrence of those with practical experience in cement manufacture. For example, there is a tendency in the book to belittle the value of alumina in Portland cement and it seems to be accepted that alumina behaves as little more than a flux. This would certainly not be the opinion of those who have had practical experience with cements of different compositions. The suggestion that all the sulphur from coal and raw materials leaving a rotary kiln is in the form of sulphur trioxide, and that most of it passes away with the flue dust, is again not in accordance with practical experience.

A table of strengths of rapid-hardening cements, including the best-known brands in the world, shows figures which are well below those applying to modern cements, and although the object of displaying the table may have been to give correlation with chemical composition it is unfortunate that the heading should suggest that it is representative of modern strengths. There is a somewhat similar lapse in the table of analyses of white cements, where the iron oxide content of five cements from three different countries is shown to range from 0.53 to 0.89 per cent. It is doubtful whether there is any white cement worthy of the name on the market containing more than 0.6 per cent. iron oxide. At a time when there seems some possibility of pozzolana cements, i.e., mixtures of Portland cement with pozzolana, finding a place in the industry, it is unfortunate that the term "pozzolana cement" should be used for mixtures of hydrated lime and pozzolana.

The book does not attempt to deal in detail with the practical side of cement manufacture, but, in addition to the section on constitution and the changes during burning and hardening, there are chapters dealing with pozzolana, aluminous and slag cements, the resistance of cement to attack by chemicals and certain natural waters, concrete aggregates, etc.

This book is essentially a compilation from the literature on the subject, but the information from numerous sources is very well presented to make an

easily readable statement of the present position of cement chemistry. The references are as complete as could be desired. The names of the authors alone are a guarantee of dependable and accurate statements from the theoretical standpoint; it is, in fact, only on the more practical points that criticism can be offered.

Specific Heats of Raw Materials for Cement.

As correct values of the specific heats of raw materials are important for the calculation of heat balances for rotary kilns they have been redetermined more accurately by H. E. Schweite and H. E. von Gronow (*Zement*, 1935, p. 197), with the following results:—

Degrees Centigrade.	$CaCO_3$	CaO	Kaolin	Meta-Kaolin	Air granulated blast-furnace slag	SiO_2 (Wietzel)
20 to 100	0.2087	0.1880	—	—	—	0.1910
,, 200	—	—	—	—	—	0.2072
,, 300	0.2341	0.2010	0.2684	0.2248	0.2156	0.2196
,, 400	0.2435	—	0.2772	0.2341	0.2233	0.2321
,, 500	0.2512	0.2057	0.290	0.2414	0.2258	0.2460
,, 600	0.2580	—	—	0.2462	0.2301	0.2559
,, 700	0.2623	0.2109	—	0.2501	0.2373	0.2587
,, 800	0.2644	—	—	0.2540	0.2406	0.2608
,, 900	0.2657	0.2129	—	0.2580	0.2434	0.2630
,, 1,000	—	—	—	0.2608	0.2458	0.2644
,, 1,100	—	0.2153	—	0.2651	0.2498	0.2665
,, 1,200	—	—	—	0.2671	0.2565	0.2670
,, 1,300	—	0.2170	—	0.2684	0.2773	0.2698
,, 1,400	—	—	—	(0.270)	—	0.2704
,, 1,500	—	0.2185	—	—	—	(0.2717)

The results may be interpolated. To find the specific heat of a clay all the Al_2O_3 is taken as kaolin according to the equation kaolin $= 2.53 \times \%Al_2O_3$, meta-kaolin $= 2.18 \times \%Al_2O_3$. The silica combined with this is equal to $1.18 \times \%Al_2O_3$, and this value is subtracted from the total silica to obtain the free silica. From the table the mean specific heats of these two materials can be read off and the heat content calculated in the usual way. The heat content of the $CaCO_3$ can also be calculated from the specific heat given in the table. The sum of the heats in these three components gives the heat in the raw material. The small amounts of other substances can be neglected without appreciably affecting the result.

Portland Cement and Sulphuric Acid from Gypsum and Clay. By P. P. Budnikoff and M. P. Jukoff. (*Tonindustrie Zeitung*, 1935, p. 65).—The paper deals with the method of preparing a heat balance for the manufacture of Portland cement and sulphuric acid using gypsum and clay as raw materials.

Gas Volumes per Ton of Clinker and Gas Velocities in Rotary Kilns.

THE tables and data are based on the following assumptions:

(1) Slurry—

$CaCO_3 = 77$ per cent.; $MgCO_3 = 1$ per cent.; loss on ignition = 36.4 per cent.; free water in slurry = 40 per cent.; combined water in slurry = 0.8 per cent.; organic matter = 1.2 per cent.

(2) Coal—

Moisture = 7 per cent.; standard coal factor = 0.887.

Standard coal = theoretical dry coal with a calorific value of 7,000 calories.

Let m = per cent. moisture in raw coal,

B = calorific value of dry coal,

then standard coal factor $= F = \frac{B(100-m)}{7{,}000 \times 100}$

The production of one ton of clinker corresponds to $\frac{m \times N \times 2{,}240}{10{,}000 \times F}$ lb. of coal moisture.

where m = per cent. moisture in raw coal,

N = per cent. standard coal, and

F = standard coal factor.

In this case the formula reduces to $1.768 \times N$.

The oxygen in the kiln exit-gas is assumed to be 1 per cent. by volume.

Gases obtained from 1 lb. of Standard Coal.

Standard coal analysis—Carbon	.. ..	73.5	per cent.
Hydrogen	.. ..	4.7	,,
Nitrogen	.. ..	1.4	,,
Sulphur	.. ..	1.9	,,
Oxygen	.. ..	7.5	,,
Ash ..	.. ..	11.0	,,
		100.0	,,

The products of combustion will comprise

$CO_2 = C \times \frac{44}{12} = 0.735 \times \frac{44}{12} = 2.695$ lb. per lb. of standard coal.

$SO_2 = S \times \frac{64}{32} = 0.019 \times \frac{64}{32} = 0.038$,, ,, ,,

$H_2O = H \times \frac{18}{2} = 0.047 \times \frac{18}{2} = 0.423$,, ,, ,,

N_2 = 0.014 plus N_2 contained in air used for combustion.

The oxygen required for

$CO_2 = C \times \frac{32}{12} = 1.960$ lb. per lb. of standard coal.

$SO_2 = S \times \frac{32}{32} = 0.019$,, ,, ,,

$H_2O = H \times \frac{16}{2} = 0.376$,, ,, ,,

Deduct oxygen in coal = 0.075 ,, ..

Thus total oxygen required = 2.280 lb. per lb. of standard coal.

Nitrogen in air required = $2.28 \times \frac{77}{23} = 7.64$ lb. per pound of standard coal.

If we add 0.014 for the nitrogen in the coal we get 7.654 lb. as the amount of nitrogen per pound of standard coal.

Calculation of Weight of Gases from Slurry when one Ton of Clinker is Produced.

It may be taken that on average every 100 lb. of clinker contains 2.2 lb. of coal ash. The dust losses may be taken as 2.5 per cent. of clinker (assumed to be dry slurry). Therefore when 100 lb. of clinker is produced the dry slurry required is

$$2.5 + \frac{100 \times 97.8}{100 - \text{per cent. loss on ignition}} = 156.3 \text{ lb.}$$

Whence for one ton of clinker the dry slurry required is 3,500 lb. The gases from the slurry are therefore:

	lb.
(1) Steam from free water	2,333
(2) Steam from combined water	28
(3) Steam from combustion of organic matter	26
(4) Carbon dioxide from calcium carbonate decomposition	1,186
(5) Carbon dioxide from magnesium carbonate decomposition	18
(6) Carbon dioxide from combustion of organic matter	92
(7) Nitrogen from air of organic combustion	262
Total	3,945
Total steam	2,387
Total carbon dioxide	1,296

Organic matter is considered as peat in these calculations, and the analysis assumed is

Carbon	60 per cent. of organic matter.
Hydrogen	7 „ „ „
Oxygen	30 „ „ „

Therefore the combustion of 1 lb. of organic matter will yield

Carbon dioxide	2.2 lb.
Water	0.63 „
Nitrogen	6.24 „

Excess Air.

OXYGEN IN EXIT GASES = 1 PER CENT.

A table connecting standard coal consumption, oxygen in exit gases and percentage of excess air is given by Gilbert in CEMENT AND CEMENT MANUFACTURE, page 1476, 1930, from which column (2) in the following table is taken.

Column (3) = lb. excess air per lb. of coal. As 1 lb. of standard coal requires 9.92 lb. of air for combustion, the weight of excess air per pound of standard coal is $\frac{9.92 \times \text{per cent. excess air}}{100}$ lb.

Column (4) is obtained by multiplying column (3) by the weight in pounds of the coal needed in the production of 1 ton of clinker.

Columns (5) and (6) : The nitrogen in the excess air is obtained by multiplying by the factor 0.768. The oxygen is obtained by difference.

(1) Standard coal consumption.	(2) Excess air.	(3) Excess air per lb. coal.	(4) Excess air per ton of clinker.	(5) Nitrogen in excess air.	(6) Oxygen in excess air.
20.0 per cent.	5.70 per cent.	0.5655 lb.	250.5 lb.	192.4 lb.	58.1 lb.
20.5 ,,	5.68 ,,	0.5633 ,,	255.9 ,,	196.5 ,,	59.4 ,,
21.0 ,,	5.66 ,,	0.5611 ,,	261.3 ,,	200.7 ,,	60.6 ,,
21.5 ,,	5.64 ,,	0.5590 ,,	266.7 ,,	204.8 ,,	61.9 ,,
22.0 ,,	5.62 ,,	0.5570 ,,	272.1 ,,	209.0 ,,	63.1 ,,
22.5 ,,	5.61 ,,	0.5559 ,,	277.5 ,,	213.1 ,,	64.4 ,,
23.0 ,,	5.59 ,,	0.5536 ,,	282.9 ,,	217.3 ,,	65.6 ,,
23.5 ,,	5.57 ,,	0.5514 ,,	288.3 ,,	221.4 ,,	66.9 ,,
24.0 ,,	5.56 ,,	0 5502 ,,	293.7 ,,	225.6 ,,	68.1 ,,
24.5 ,,	5.55 ,,	0.5492 ,,	299.1 ,,	229.7 ,,	69.4 ,,
25.0 ,,	5.54 ,,	0.5482 ,,	304.5 ,,	233.9 ,,	70.6 ,,
25.5 ,,	5.52 ,,	0.5462 ,,	309.8 ,,	237.9 ,,	71.9 ,,
26.0 ,,	5.50 ,,	0.5453 ,,	315.0 ,,	241.9 ,,	73.1 ,,
26.5 ,,	5.49 ,,	0.5443 ,,	320.3 ,,	246.0 ,,	74.3 ,,
27.0 ,,	5.48 ,,	0.5432 ,,	325.5 ,,	250.0 ,,	75.5 ,,
27.5 ,,	5.47 ,,	0.5422 ,,	330.7 ,,	254.0 ,,	76.7 ,,
28.0 ,,	5.46 ,,	0.5413 ,,	336.0 ,,	258.1 ,,	77.9 ,,
28.5 ,,	5.45 ,,	0.5404 ,,	341.3 ,,	262.2 ,,	79.1 ,,
29.0 ,,	5.44 ,,	0.5394 ,,	346.6 ,,	266.3 ,,	80.3 ,,
29.5 ,,	5.43 ,,	0.5383 ,,	351.9 ,,	270.4 ,,	81.5 ,,
30.0 ,,	5.42 ,,	0.5373 ,,	357 3 ,,	274.5 ,,	82.8 ,,

WEIGHTS OF KILN EXIT-GASES AT VARIOUS PERCENTAGES OF STANDARD COAL.
(1 per cent. oxygen is assumed and the corresponding nitrogen is allowed for.)

Standard coal consumption.	lb. per ton of clinker.						
	Standard coal.	Carbon dioxide.	Steam.	Sulphur dioxide.	Oxygen.	Nitrogen.	Total.
20.0 per cent.	448.0	2,504	2,611	17	58	3,882	9,072
20.5 ,,	459.2	2,534	2,617	17	59	3,972	9,199
21.0 ,,	470.4	2,564	2,622	18	61	4,062	9,327
21.5 ,,	481.6	2,594	2,628	18	62	4,151	9,463
22.0 ,,	492.8	2,625	2,633	19	63	4,241	9,591
22.5 ,,	504.0	2,655	2,639	19	64	4,331	9,718
23.0 ,,	515.2	2,685	2,645	20	66	4,421	9,847
23.5 ,,	526.4	2,715	2,650	20	67	4,511	9,973
24.0 ,,	537.6	2,745	2,656	20	68	4,600	10,099
24.5 ,,	548.8	2,775	2,661	21	69	4,690	10,226
25.0 ,,	560.0	2,806	2,667	21	71	4,780	10,355
25.5 ,,	571.2	2,836	2,673	22	72	4,870	10,483
26.0 ,,	582.4	2,866	2,678	22	73	4,960	10,609
26.5 ,,	593.6	2,896	2,684	23	74	5,049	10,736
27.0 ,,	604.8	2,926	2,690	23	76	5,139	10,864
27.5 ,,	616.0	2,956	2,695	23	77	5,229	10,990
28.0 ,,	627.2	2,986	2,701	24	78	5,319	11,118
28.5 ,,	638.4	3,017	2,706	24	79	5,409	11,245
29.0 ,,	649.6	3,047	2,712	25	80	5,498	11,372
29.5 ,,	660.8	3,077	2,718	25	82	5,588	11,500
30.0 ,,	672.0	3,107	2,723	25	83	5,678	11,626

VOLUMES OF KILN EXIT GASES (CUBIC FEET PER TON OF CLINKER) AT VARIOUS PERCENTAGES OF STANDARD COAL AND VARIOUS EXIT-GAS TEMPERATURES.

Temp. deg. F.	Standard coal consumption (per cent.).										
	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0
450 ..	226,731	229,554	232,371	235,171	237,982	240,805	243,658	246,444	249,278	252,041	254,876
475 ..	233,008	235,910	238,805	241,683	244,573	247,472	250,405	253,266	256,180	259,018	261,933
500 ..	239,285	242,266	245,239	248,195	251,164	254,139	257,152	260,088	263,082	265,995	268,990
525 ..	245,562	248,622	251,673	254,707	257,755	260,806	263,899	266,910	269,984	272,972	276,047
550 ..	251,839	254,978	258,107	261,219	264,346	267,473	270,646	273,732	276,886	279,949	283,104
575 ..	258,116	261,334	264,541	267,731	270,937	274,140	277,393	280,554	283,788	286,926	290,161
600 ..	264,393	267,690	270,975	274,243	277,528	280,807	284,140	287,376	290,690	293,903	297,218
625 ..	270,670	274,046	277,409	280,755	284,119	287,474	290,887	294,198	297,592	300,880	304,275
650 ..	276,947	280,402	283,843	287,267	290,710	294,141	297,634	301,020	304,494	307,857	311,332
675 ..	283,224	286,758	290,277	293,779	297,301	300,808	304,381	307,842	311,396	314,834	318,389
700 ..	289,501	293,114	296,711	300,291	303,892	307,475	311,128	314,664	318,298	321,811	325,446
725 ..	295,778	299,470	303,145	306,803	310,483	314,142	317,875	321,486	325,200	328,788	332,503
750 ..	302,055	305,826	309,579	313,315	317,074	320,809	324,622	328,308	332,102	335,768	339,560

Temp. deg. F.	Standard coal consumption (per cent.).									
	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0
450 ..	257,709	260,495	263,305	266,148	268,934	271,767	274,568	277,378	280,220	283,006
475 ..	264,845	267,708	270,596	273,517	276,380	279,293	282,171	285,059	287,979	290,842
500 ..	271,981	274,921	277,887	280,886	283,826	286,819	289,774	292,740	295,738	298,678
525 ..	279,117	282,134	285,178	288,255	291,272	294,345	297,377	300,421	303,497	306,514
550 ..	286,253	289,347	292,469	295,624	298,718	301,871	304,980	308,102	311,256	314,350
575 ..	293,389	296,560	299,760	302,993	306,164	309,397	312,583	315,783	319,015	322,186
600 ..	300,525	303,773	307,051	310,362	313,610	316,923	320,186	323,464	326,774	330,022
625 ..	307,661	310,986	314,342	317,731	321,056	324,449	327,789	331,145	334,533	337,858
650 ..	314,797	318,199	321,633	325,100	328,502	331,975	335,392	338,826	342,292	345,694
675 ..	321,933	325,412	328,924	332,469	335,948	339,501	342,995	346,507	350,051	353,530
700 ..	329,069	332,625	336,215	339,838	343,394	347,027	350,598	354,188	357,810	361,336
725 ..	336,205	339,838	343,506	347,207	350,840	354,553	358,201	361,869	365,569	369,202
750 ..	343,341	347,051	350,797	354,576	358,286	362,079	365,804	369,550	373,328	377,038

Kiln Data.

Diameter of kiln.	Cross-section kiln.	Assumed output.		
		Clinker per hour.	Clinker per minute.	Per hour per ft. of diameter.
7.0 ft.	38.48 sq. ft.	5 tons	0.08333 tons	0.7143 tons
7.5 ,,	44.18 ,,	6 ,,	0.10000 ,,	0.8000 ,,
8.0 ,,	50.26 ,,	7 ,,	0.1167 ,,	0.8750 ,,
8.5 ,,	56.74 ,,	8 ,,	0.1333 ,,	0.9412 ,,
9.0 ,,	63.62 ,,	9 ,,	0.1500 ,,	1.0000 ,,
9.5 ,,	70.88 ,,	10 ,,	0.1667 ,,	1.0526 ,,
10.0 ,,	78.54 ,,	11 ,,	0.1833 ,,	1.1000 ,,
10.5 ,,	86.59 ,,	12 ,,	0.2000 ,,	1.1428 ,,
11.0 ,,	95.03 ,,	13 ,,	0.2167 ,,	1.1818 ,,
11.5 ,,	103.90 ,,	14 ,,	0.2333 ,,	1.2174 ,,
12.0 ,,	113.10 ,,	15 ,,	0.2500 ,,	1.2500 ,,

GAS VELOCITIES IN LINEAR FEET PER MINUTE IN KILNS AT GAS TEMPERATURES BETWEEN 450 AND 750 DEG. F. AND AT COAL CONSUMPTIONS BETWEEN 20 AND 30 PER CENT.

With the aid of the data given previously we are now able to calculate gas velocities from the formula

$$\text{Gas velocity in linear feet per minute} = \frac{\text{Cubic feet gas per ton of clinker} \times \text{kiln output in tons per minute}}{\text{Cross-section of kiln in square feet.}}$$

FOR A 7-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	492 feet per minute	25.5 per cent.	558 feet per minute
20.5 ,,	498 ,, ,,	26.0 ,,	564 ,, ,,
21.0 ,,	504 ,, ,,	26.5 ,,	570 ,, ,,
21.5 ,,	510 ,, ,,	27.0 ,,	576 ,, ,,
22.0 ,,	516 ,, ,,	27.5 ,,	582 ,, ,,
22.5 ,,	522 ,, ,,	28.0 ,,	588 ,, ,,
23.0 ,,	528 ,, ,,	28.5 ,,	594 ,, ,,
23.5 ,,	534 ,, ,,	29.0 ,,	600 ,, ,,
24.0 ,,	540 ,, ,,	29.5 ,,	606 ,, ,,
24.5 ,,	546 ,, ,,	30.0 ,,	613 ,, ,,
25.0 ,,	552 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	13.6 feet per minute	25.5 per cent.	15.5 feet per minute
20.5 ,,	13.8 ,, ,,	26.0 ,,	15.7 ,, ,,
21.0 ,,	13.9 ,, ,,	26.5 ,,	15.8 ,, ,,
21.5 ,,	14.1 ,, ,,	27.0 ,,	16.0 ,, ,,
22.0 ,,	14.2 ,, ,,	27.5 ,,	16.2 ,, ,,
22.5 ,,	14.4 ,, ,,	28.0 ,,	16.3 ,, ,,
23.0 ,,	14.6 ,, ,,	28.5 ,,	16.5 ,, ,,
23.5 ,,	14.7 ,, ,,	29.0 ,,	16.7 ,, ,,
24.0 ,,	14.9 ,, ,,	29.5 ,,	16.8 ,, ,,
24.5 ,,	15.1 ,, ,,	30.0 ,,	17.0 ,, ,,
25.0 ,,	15.3 ,, ,,		

7½-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	513 feet per minute	25.5 per cent.	583 feet per minute
20.5 ,,	520 ,, ,,	26.0 ,,	590 ,, ,,
21.0 ,,	526 ,, ,,	26.5 ,,	596 ,, ,,
21.5 ,,	532 ,, ,,	27.0 ,,	603 ,, ,,
22.0 ,,	539 ,, ,,	27.5 ,,	609 ,, ,,
22.5 ,,	545 ,, ,,	28.0 ,,	615 ,, ,,
23.0 ,,	551 ,, ,,	28.5 ,,	622 ,, ,,
23.5 ,,	558 ,, ,,	29.0 ,,	628 ,, ,,
24.0 ,,	564 ,, ,,	29.5 ,,	634 ,, ,,
24.5 ,,	571 ,, ,,	30.0 ,,	640 ,, ,,
25.0 ,,	577 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.2 feet per minute	25.5 per cent.	16.2 feet per minute
20.5 ,,	14.4 ,, ,,	26.0 ,,	16.4 ,, ,,
21.0 ,,	14.6 ,, ,,	26.5 ,,	16.6 ,, ,,
21.5 ,,	14.7 ,, ,,	27.0 ,,	16.7 ,, ,,
22.0 ,,	14.9 ,, ,,	27.5 ,,	16.9 ,, ,,
22.5 ,,	15.1 ,, ,,	28.0 ,,	17.0 ,, ,,
23.0 ,,	15.2 ,, ,,	28.5 ,,	17.1 ,, ,,
23.5 ,,	15.4 ,, ,,	29.0 ,,	17.3 ,, ,,
24.0 ,,	15.6 ,, ,,	29.5 ,,	17.5 ,, ,,
24.5 ,,	15.8 ,, ,,	30.0 ,,	17.7 ,, ,,
25.0 ,,	16.0 ,, ,,		

8-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	527 feet per minute	25.5 per cent.	598 feet per minute
20.5 ,,	533 ,, ,,	26.0 ,,	604 ,, ,,
21.0 ,,	539 ,, ,,	26.5 ,,	611 ,, ,,
21.5 ,,	546 ,, ,,	27.0 ,,	617 ,, ,,
22.0 ,,	552 ,, ,,	27.5 ,,	624 ,, ,,
22.5 ,,	559 ,, ,,	28.0 ,,	630 ,, ,,
23.0 ,,	565 ,, ,,	28.5 ,,	637 ,, ,,
23.5 ,,	572 ,, ,,	29.0 ,,	643 ,, ,,
24.0 ,,	579 ,, ,,	29.5 ,,	650 ,, ,,
24.5 ,,	585 ,, ,,	30.0 ,,	656 ,, ,,
25.0 ,,	592 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.6 feet per minute	25.5 per cent.	16.6 feet per minute
20.5 ,,	14.8 ,, ,,	26.0 ,,	16.8 ,, ,,
21.0 ,,	15.0 ,, ,,	26.5 ,,	17.0 ,, ,,
21.5 ,,	15.1 ,, ,,	27.0 ,,	17.2 ,, ,,
22.0 ,,	15.3 ,, ,,	27.5 ,,	17.3 ,, ,,
22.5 ,,	15.5 ,, ,,	28.0 ,,	17.5 ,, ,,
23.0 ,,	15.7 ,, ,,	28.5 ,,	17.6 ,, ,,
23.5 ,,	15.9 ,, ,,	29.0 ,,	17.8 ,, ,,
24.0 ,,	16.0 ,, ,,	29.5 ,,	18.0 ,, ,,
24.5 ,,	16.2 ,, ,,	30.0 ,,	18.2 ,, ,,
25.0 ,,	16.4 ,, ,,		

8½-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	533 feet per minute	25.5 per cent.	605 feet per minute
20.5 ,,	540 ,, ,,	26.0 ,,	612 ,, ,,
21.0 ,,	546 ,, ,,	26.5 ,,	618 ,, ,,
21.5 ,,	553 ,, ,,	27.0 ,,	625 ,, ,,
22.0 ,,	560 ,, ,,	27.5 ,,	632 ,, ,,
22.5 ,,	566 ,, ,,	28.0 ,,	638 ,, ,,
23.0 ,,	573 ,, ,,	28.5 ,,	645 ,, ,,
23.5 ,,	579 ,, ,,	29.0 ,,	651 ,, ,,
24.0 ,,	586 ,, ,,	29.5 ,,	658 ,, ,,
24.5 ,,	592 ,, ,,	30.0 ,,	665 ,, ,,
25.0 ,,	599 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.7 feet per minute	25.5 per cent.	16.6 feet per minute
20.5 ,,	14.9 ,, ,,	26.0 ,,	16.8 ,, ,,
21.0 ,,	15.0 ,, ,,	26.5 ,,	17.0 ,, ,,
21.5 ,,	15.2 ,, ,,	27.0 ,,	17.2 ,, ,,
22.0 ,,	15.4 ,, ,,	27.5 ,,	17.4 ,, ,,
22.5 ,,	15.6 ,, ,,	28.0 ,,	17.5 ,, ,,
23.0 ,,	15.7 ,, ,,	28.5 ,,	17.7 ,, ,,
23.5 ,,	15.9 ,, ,,	29.0 ,,	17.9 ,, ,,
24.0 ,,	16.1 ,, ,,	29.5 ,,	18.1 ,, ,,
24.5 ,,	16.3 ,, ,,	30.0 ,,	18.3 ,, ,,
25.0 ,,	16.4 ,, ,,		

9-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	533 feet per minute	25.5 per cent.	606 feet per minute
20.5 ,,	540 ,, ,,	26.0 ,,	612 ,, ,,
21.0 ,,	546 ,, ,,	26.5 ,,	619 ,, ,,
21.5 ,,	553 ,, ,,	27.0 ,,	626 ,, ,,
22.0 ,,	559 ,, ,,	27.5 ,,	632 ,, ,,
22.5 ,,	566 ,, ,,	28.0 ,,	639 ,, ,,
23.0 ,,	572 ,, ,,	28.5 ,,	645 ,, ,,
23.5 ,,	579 ,, ,,	29.0 ,,	652 ,, ,,
24.0 ,,	586 ,, ,,	29.5 ,,	659 ,, ,,
24.5 ,,	592 ,, ,,	30.0 ,,	665 ,, ,,
25.0 ,,	599 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.7 feet per minute	25.5 per cent.	16.7 feet per minute
20.5 ,,	14.9 ,, ,,	26.0 ,,	16.9 ,, ,,
21.0 ,,	15.1 ,, ,,	26.5 ,,	17.1 ,, ,,
21.5 ,,	15.3 ,, ,,	27.0 ,,	17.3 ,, ,,
22.0 ,,	15.5 ,, ,,	27.5 ,,	17.5 ,, ,,
22.5 ,,	15.7 ,, ,,	28.0 ,,	17.7 ,, ,,
23.0 ,,	15.8 ,, ,,	28.5 ,,	17.8 ,, ,,
23.5 ,,	16.0 ,, ,,	29.0 ,,	18.0 ,, ,,
24.0 ,,	16.2 ,, ,,	29.5 ,,	18.2 ,, ,,
24.5 ,,	16.4 ,, ,,	30.0 ,,	18.4 ,, ,,
25.0 ,,	16.6 ,, ,,		

9½-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	533 feet per minute	25.5 per cent.	606 feet per minute
20.5 ,,	540 ,, ,,	26.0 ,,	613 ,, ,,
21.0 ,,	546 ,, ,,	26.5 ,,	619 ,, ,,
21.5 ,,	553 ,, ,,	27.0 ,,	626 ,, ,,
22.0 ,,	560 ,, ,,	27.5 ,,	632 ,, ,,
22.5 ,,	566 ,, ,,	28.0 ,,	639 ,, ,,
23.0 ,,	573 ,, ,,	28.5 ,,	646 ,, ,,
23.5 ,,	580 ,, ,,	29.0 ,,	652 ,, ,,
24.0 ,,	586 ,, ,,	29.5 ,,	659 ,, ,,
24.5 ,,	593 ,, ,,	30.0 ,,	667 ,, ,,
25.0 ,,	599 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.7 feet per minute	25.5 per cent.	16.7 feet per minute
20.5 ,,	14.9 ,, ,,	26.0 ,,	16.9 ,, ,,
21.0 ,,	15.1 ,, ,,	26.5 ,,	17.1 ,, ,,
21.5 ,,	15.3 ,, ,,	27.0 ,,	17.3 ,, ,,
22.0 ,,	15.5 ,, ,,	27.5 ,,	17.5 ,, ,,
22.5 ,,	15.7 ,, ,,	28.0 ,,	17.7 ,, ,,
23.0 ,,	15.8 ,, ,,	28.5 ,,	17.8 ,, ,,
23.5 ,,	16.0 ,, ,,	29.0 ,,	18.0 ,, ,,
24.0 ,,	16.2 ,, ,,	29.5 ,,	18.2 ,, ,,
24.5 ,,	16.4 ,, ,,	30.0 ,,	18.4 ,, ,,
25.0 ,,	16.6 ,, ,,		

10-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	529 feet per minute	25.5 per cent.	602 feet per minute
20.5 ,,	536 ,, ,,	26.0 ,,	609 ,, ,,
21.0 ,,	542 ,, ,,	26.5 ,,	615 ,, ,,
21.5 ,,	549 ,, ,,	27.0 ,,	622 ,, ,,
22.0 ,,	556 ,, ,,	27.5 ,,	628 ,, ,,
22.5 ,,	562 ,, ,,	28.0 ,,	635 ,, ,,
23.0 ,,	569 ,, ,,	28.5 ,,	641 ,, ,,
23.5 ,,	576 ,, ,,	29.0 ,,	648 ,, ,,
24.0 ,,	582 ,, ,,	29.5 ,,	655 ,, ,,
24.5 ,,	589 ,, ,,	30.0 ,,	661 ,, ,,
25.0 ,,	595 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.6 feet per minute	25.5 per cent.	16.6 feet per minute
20.5 ,,	14.8 ,, ,,	26.0 ,,	16.8 ,, ,,
21.0 ,,	15.0 ,, ,,	26.5 ,,	17.0 ,, ,,
21.5 ,,	15.2 ,, ,,	27.0 ,,	17.2 ,, ,,
22.0 ,,	15.4 ,, ,,	27.5 ,,	17.4 ,, ,,
22.5 ,,	15.6 ,, ,,	28.0 ,,	17.5 ,, ,,
23.0 ,,	15.7 ,, ,,	28.5 ,,	17.7 ,, ,,
23.5 ,,	15.9 ,, ,,	29.0 ,,	17.9 ,, ,,
24.0 ,,	16.1 ,, ,,	29.5 ,,	18.0 ,, ,,
24.5 ,,	16.3 ,, ,,	30.0 ,,	18.2 ,, ,,
25.0 ,,	16.5 ,, ,,		

10½-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	524 feet per minute	25.5 per cent.	596 feet per minute
20.5 ,,	531 ,, ,,	26.0 ,,	602 ,, ,,
21.0 ,,	537 ,, ,,	26.5 ,,	609 ,, ,,
21.5 ,,	543 ,, ,,	27.0 ,,	615 ,, ,,
22.0 ,,	550 ,, ,,	27.5 ,,	621 ,, ,,
22.5 ,,	556 ,, ,,	28.0 ,,	628 ,, ,,
23.0 ,,	563 ,, ,,	28.5 ,,	634 ,, ,,
23.5 ,,	570 ,, ,,	29.0 ,,	641 ,, ,,
24.0 ,,	576 ,, ,,	29.5 ,,	647 ,, ,,
24.5 ,,	583 ,, ,,	30.0 ,,	654 ,, ,,
25.0 ,,	589 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.5 feet per minute	25.5 per cent.	16.5 feet per minute
20.5 ,,	14.7 ,, ,,	26.0 ,,	16.6 ,, ,,
21.0 ,,	14.8 ,, ,,	26.5 ,,	16.8 ,, ,,
21.5 ,,	15.0 ,, ,,	27.0 ,,	17.0 ,, ,,
22.0 ,,	15.2 ,, ,,	27.5 ,,	17.2 ,, ,,
22.5 ,,	15.4 ,, ,,	28.0 ,,	17.4 ,, ,,
23.0 ,,	15.6 ,, ,,	28.5 ,,	17.5 ,, ,,
23.5 ,,	15.8 ,, ,,	29.0 ,,	17.7 ,, ,,
24.0 ,,	15.9 ,, ,,	29.5 ,,	17.9 ,, ,,
24.5 ,,	16.1 ,, ,,	30.0 ,,	18.1 ,, ,,
25.0 ,,	16.3 ,, ,,		

11-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	517 feet per minute	25.5 per cent.	588 feet per minute
20.5 ,,	523 ,, ,,	26.0 ,,	594 ,, ,,
21.0 ,,	530 ,, ,,	26.5 ,,	600 ,, ,,
21.5 ,,	536 ,, ,,	27.0 ,,	607 ,, ,,
22.0 ,,	543 ,, ,,	27.5 ,,	613 ,, ,,
22.5 ,,	549 ,, ,,	28.0 ,,	620 ,, ,,
23.0 ,,	556 ,, ,,	28.5 ,,	626 ,, ,,
23.5 ,,	562 ,, ,,	29.0 ,,	633 ,, ,,
24.0 ,,	568 ,, ,,	29.5 ,,	640 ,, ,,
24.5 ,,	575 ,, ,,	30.0 ,,	646 ,, ,,
25.0 ,,	581 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.3 feet per minute	25.5 per cent.	16.3 feet per minute
20.5 ,,	14.5 ,, ,,	26.0 ,,	16.4 ,, ,,
21.0 ,,	14.6 ,, ,,	26.5 ,,	16.6 ,, ,,
21.5 ,,	14.8 ,, ,,	27.0 ,,	16.8 ,, ,,
22.0 ,,	15.0 ,, ,,	27.5 ,,	17.0 ,, ,,
22.5 ,,	15.2 ,, ,,	28.0 ,,	17.2 ,, ,,
23.0 ,,	15.4 ,, ,,	28.5 ,,	17.3 ,, ,,
23.5 ,,	15.6 ,, ,,	29.0 ,,	17.5 ,, ,,
24.0 ,,	15.7 ,, ,,	29.5 ,,	17.7 ,, ,,
24.5 ,,	15.9 ,, ,,	30.0 ,,	17.9 ,, ,,
25.0 ,,	16.1 ,, ,,		

11½-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	509 feet per minute	25.5 per cent.	579 feet per minute
20.5 ,,	516 ,, ,,	26.0 ,,	585 ,, ,,
21.0 ,,	522 ,, ,,	26.5 ,,	591 ,, ,,
21.5 ,,	528 ,, ,,	27.0 ,,	598 ,, ,,
22.0 ,,	535 ,, ,,	27.5 ,,	604 ,, ,,
22.5 ,,	541 ,, ,,	28.0 ,,	610 ,, ,,
23.0 ,,	547 ,, ,,	28.5 ,,	617 ,, ,,
23.5 ,,	554 ,, ,,	29.0 ,,	623 ,, ,,
24.0 ,,	560 ,, ,,	29.5 ,,	629 ,, ,,
24.5 ,,	566 ,, ,,	30.0 ,,	636 ,, ,,
25.0 ,,	573 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	14.1 feet per minute	25.5 per cent.	16.1 feet per minute
20.5 ,,	14.2 ,, ,,	26.0 ,,	16.2 ,, ,,
21.0 ,,	14.4 ,, ,,	26.5 ,,	16.4 ,, ,,
21.5 ,,	14.6 ,, ,,	27.0 ,,	16.6 ,, ,,
22.0 ,,	14.8 ,, ,,	27.5 ,,	16.8 ,, ,,
22.5 ,,	15.0 ,, ,,	28.0 ,,	17.0 ,, ,,
23.0 ,,	15.2 ,, ,,	28.5 ,,	17.1 ,, ,,
23.5 ,,	15.4 ,, ,,	29.0 ,,	17.3 ,, ,,
24.0 ,,	15.5 ,, ,,	29.5 ,,	17.4 ,, ,,
24.5 ,,	15.7 ,, ,,	30.0 ,,	17.6 ,, ,,
25.0 ,,	15.9 ,, ,,		

12-FT. DIAMETER KILN WITH GAS TEMPERATURE OF 450 DEG. F.

Coal consumption.	Velocity of gases.	Coal consumption.	Velocity of gases.
20.0 per cent.	501 feet per minute	25.5 per cent.	569 feet per minute
20.5 ,,	507 ,, ,,	26.0 ,,	576 ,, ,,
21.0 ,,	513 ,, ,,	26.5 ,,	582 ,, ,,
21.5 ,,	519 ,, ,,	27.0 ,,	588 ,, ,,
22.0 ,,	525 ,, ,,	27.5 ,,	594 ,, ,,
22.5 ,,	532 ,, ,,	28.0 ,,	601 ,, ,,
23.0 ,,	538 ,, ,,	28.5 ,,	607 ,, ,,
23.5 ,,	545 ,, ,,	29.0 ,,	613 ,, ,,
24.0 ,,	551 ,, ,,	29.5 ,,	619 ,, ,,
24.5 ,,	557 ,, ,,	30.0 ,,	626 ,, ,,
25.0 ,,	563 ,, ,,		

Temperature Correction Table.—To obtain the gas velocity at any other temperature use the following :

Coal consumption.	Add for each 25 deg. F. rise in temperature.	Coal consumption.	Add for each 25 deg. F. rise in temperature.
20.0 per cent.	13.9 feet per minute	25.5 per cent.	15.8 feet per minute
20.5 ,,	14.1 ,, ,,	26.0 ,,	16.0 ,, ,,
21.0 ,,	14.3 ,, ,,	26.5 ,,	16.2 ,, ,,
21.5 ,,	14.4 ,, ,,	27.0 ,,	16.4 ,, ,,
22.0 ,,	14.6 ,, ,,	27.7 ,,	16.5 ,, ,,
22.5 ,,	14.7 ,, ,,	28.0 ,,	16.7 ,, ,,
23.0 ,,	14.8 ,, ,,	28.5 ,,	16.8 ,, ,,
23.5 ,,	15.0 ,, ,,	29.0 ,,	17.0 ,, ,,
24.0 ,,	15.2 ,, ,,	29.5 ,,	17.1 ,, ,,
24.5 ,,	15.4 ,, ,,	30.0 ,,	17.3 ,, ,,
25.0 ,,	15.6 ,, ,,		

GAS VELOCITY WHEN OUTPUT EXCEEDS THAT SPECIFIED IN FOREGOING TABLES.

Diameter of kiln.	For each ½-ton extra output increase the previous velocity by
7.0 ft.	9.5 per cent.
7.5 ,,	8.0 ,,
8.0 ,,	7.0 ,,
8.5 ,,	6.2 ,,
9.0 ,,	5.4 ,,
9.5 ,,	4.9 ,,
10.0 ,,	4.5 ,,
10.5 ,,	4.1 ,,
11.0 ,,	3.8 ,,
11.5 ,,	3.5 ,,
12.0 ,,	3.2 ,,

EXAMPLE.—It follows by the use of the tables that when the coal consumption is 27 per cent. on a 10-ft. diameter kiln with an output of 11 tons per hour the gas velocity is 760 ft. per minute at 650 deg. F. 4.5 per cent. on 760 gives a total of 794 ft. per minute = velocity at 11½ tons per hour. 4.5 per cent. on 794 gives a total of 830 ft. per minute = velocity at 12 tons per hour.

REFERENCES.

(1) Gilbert, *Cement and Cement Manufacture* (1930), p. 1472.
(2) Howe, *Cement and Cement Manufacture* (1933), pp. 149, 237.
(3) Volumes and Weights of Gases, *Archives B.P.C.R.A.*

Hydration of Calcium Silicates under the Microscope.

The hydration of pure calcium silicates mixed with 1, 3, 6, and 9 parts of water has been studied under the microscope for periods up to three months by Messrs. S. Kondo and T. Yamauchi, and the results are reported in the Journal of the Japanese Ceramic Association. The silicates were prepared by heating the constituent materials to the following temperatures: $3CaO.SiO_2$ to 1,700–1,800 deg. C.; $2CaO.SiO_2$ to 1,700 deg. C.; $3CaO.2SiO_2$ to 1,450–1,475 deg. C.; $CaO.SiO_2$ to 1,500 deg. C. $3CaO.SiO_2$ begins to hydrate after about four hours and prisms and hexagonal plates of $Ca(OH)_2$ form in four to five hours. Silicic acid gel begins to form in drops after 40 hours. $2CaO.SiO_2$ hydrates after about 40 hours with separation of silicic acid gel. There is no difference between the action of water and lime water. As the amount of water was reduced the crystal and gel formation was increased. No changes within the period of three months were observed with $3CaO.2SiO_2$ and $CaO.SiO_2$.

Clinker Rings in Rotary Kilns. By F. Kremer. (*Tonindustrie Zeitung*, 1935, p. 199).—The causes of clinker rings are (1) High ash content of the coal, especially if the ash has a low melting point, e.g., a proportion of 20 per cent. of ash is almost certain to cause clinker rings, (2) insufficient grinding of the coal, (3) irregular lime content in the raw material, (4) insufficient fineness of the raw material, (5) admission of hot air from the cooler. Kilns with enlarged burning zones usually have less tendency to form rings. Coarse coal and a short burning zone induce rings.

Fineness of Portland Cement.

By W. WATSON, B.Sc., and Q. L. CRADDOCK, M.Sc.

UNTIL recent years the fineness of cement was determined by sieves, but increase in the fineness of grinding renders sieve analysis practically useless for estimating the true fineness of modern cement, as the residue left on the finest sieve available is only a small part of the whole. At best the sieve is a measure of the coarseness rather than the fineness of a cement, and the logical procedure would seem to be first to develop a method of separating and determining the hydraulically active material in cement. The property of modern Portland cement to harden rapidly is due largely to the speed of the chemical reaction between cement and water. To obtain rapid reaction it is necessary for the cement to contain a large proportion of very small particles, and it is the aim of cement manufacturers to grind their product so that a large proportion of the cement shall be of such particle size that rapid reaction is possible. There is therefore good reason for determining with accuracy the proportion of fine material, or "flour," in commercial cements. Moreover, since modern rapid-hardening cements leave very little residue on the finest sieve available the permissible variation from the standard aperture on these sieves must necessarily be very much reduced if comparable results are to be obtained. Wig and Pearson[1] examined many sieves and showed that several "standard" No. 200 sieves differ appreciably in their aperture values.

In cement manufacture air sifting has displaced sieving machines, and the same principle seems desirable in laboratory testing of the fineness of cements. Flourometers have been in use for many years and have proved of definite value. Until recently, however, no standard form of apparatus has been available. A review of the various types of air elutriators is given in a paper by J. C. Pearson and W. H. Sligh[2]. The Petersen apparatus was one of the earliest to be adopted for use in cement investigations. This consists of a modified form of Schone's levigating funnel, but no attempt was made to collect the fine material blown off. The disadvantages of this type of apparatus are that only 5 gr. of cement can be used for each charge and, being an "up-blast" type of elutriator, there is a tendency for the cement to choke in the throat of the separating funnel. Pearson and Sligh introduced an overhead nozzle to blow down into the apex of a cone from above, so obviating the main objection to the Petersen apparatus. A standard elutriator [3] has been devised by the Associated Portland Cement Manufacturers, Ltd., on the principle of the Pearson and Sligh apparatus and has proved to be a satisfactory instrument for works routine tests. The quantity of material lifted by the air stream is governed by the size and weight of the particles and the velocity of the air current. For the purposes of standardisation the elutriator has been calibrated with an air velocity of 21 ft. per minute in the 4-in. cylindrical tube. The material removed from the cone at this velocity is designated "flour" while the remainder is known as "grit." The quantity of

material elutriated at this velocity is a direct measure of the fineness of the cement, and as all machines are standardised by means of a sample of cement of known flour content a direct comparison of different cements as regards fineness can be obtained. The advantage of this apparatus is that both the flour and grit can be obtained with a loss of not more than 3 per cent. of the flour, the loss being due to the very fine flour passing the pores of the flannel bag used as an air filter. The elutriator is accurate to 0.5 per cent., which is the tolerance allowed on successive elutriations. By examination of the grit microscopically the completeness of the separation can be readily tested. Examination of the majority of rapid-hardening cements by this elutriator shows that they contain between 73 per cent. and 80 per cent. flour, while ordinary Portland cement contains from 60 to 67 per cent. flour.

Although this method is a useful guide in works practice, it seems necessary to have a method which will give a more detailed analysis of the cement fineness. Partly due to the difficulty in collecting the fine material and partly to the tediousness of the operation, air separation has not been proceeded with in order to separate the cement into further grades. Elutriation, as distinct from air separation, seems to promise better results, as undoubtedly better control of the separation can be secured by the use of a liquid. The liquid must of course be without action on the cement and be itself unaffected. Various types of elutriators have been devised and in each case the flow of liquid is adjusted to give the required grading. Thus the limiting size of particle carried over in the stream of liquid will be governed by the velocity of the liquid at the widest point in the elutriating vessel, larger particles falling at various velocities to the bottom of the vessel if this is cylindrical in shape or being suspended at various levels in the liquid if the vessel is conical. The chief essential is that the liquid should develop stream-line flow, at a height from the point of overflow from the vessel equal to the diameter of the vessel at its widest point. This ensures that no particle of a larger size than required is carried over at any particular speed. The attainment of this condition is dependent partly on the design of the apparatus and partly upon the liquid employed. In order to separate a cement into fractions containing particles graded between certain narrow limits of size, one of two devices may be employed: (1) A single elutriating vessel with the speed of flow of the liquid regulated by jets of various sizes in conjunction with a constant head device; (2) a series of vessels of gradually increasing dimensions, connected together to form one elutriating unit.

Of the first type the Dickson elutriator[4], employing turpentine substitute as the elutriating medium, is the most satisfactory. The apparatus consists of an elongated glass tube to which jets of various sizes can be fitted. By varying the speed of flow the coarse particles are graded in accordance with the particular speed selected. At the end of the operation the coarse residue ("core"), after being allowed to settle, is drawn off, washed with ether, dried, gently ignited, and weighed. Although no attempt is made to collect and examine the fine flour elutriated, it would be quite possible to do so at each velocity chosen and

so increase the number of fractions. The process would, however, be rather laborious.

In elutriators of the second type a constant flow of liquid through the whole apparatus is maintained by a constant head arrangement. The velocity maintained in each vessel depends upon its dimensions, and if correctly designed will give a streamline flow velocity proportional to the square of the diameter of each vessel at its widest point. The Nobel soil elutriator is of the multiple-vessel type and is fairly successful in separating cement into at least five fractions, using petroleum ether as the elutriating medium. Owing to the conical shape of the vessels eddy currents occur, but provided the velocities used are not very high these do not seriously affect the average size of particle obtained in any particular vessel. The chief objection to this apparatus is that the fractions elutriated from one vessel to the next settle at the base of the latter and do not receive a very efficient " scrubbing."

The Andrews kinetic elutriator combines both the above types of apparatus, being a train of vessels of gradually increasing size set one above the other. The flow of liquid through the apparatus is regulated by means of standard size jets set at the point of overflow from the final vessel. This apparatus exhibits the required stream-line flow in both the upper and middle classifiers when petroleum spirit is used as the elutriating medium. At each velocity chosen three fractions are obtained, (1) overflow from the upper classifier, (2) material elutriated into the upper classifier, (3) material remaining in the middle classifier. Each fraction may be collected and weighed. The average diameter of each grade may then be arrived at either by count under the microscope or by means of the obscurometer[5]. This latter apparatus is a modification of the Jackson candle turbidometer and has been standardised by the Associated Portland Cement Manufacturers, Ltd., thereby eliminating the laborious process of microscopic examination of cement flour to ascertain its particle size.

A typical analysis of a cement into fractions of various particle sizes by means of the Andrews kinetic elutriator, using only two velocities of liquid flow, is :

Per cent. by weight.	Average particle size in microns.
32.4	7.2
7.2	12.3
6.2	15.0
13.5	22.2
12.9	37.8
6.4	45.0
13.2	56.0
4.2	75.0
4.0	127.0

In these methods of separating cement into grades, the finer particles are carried away in a stream of liquid. Attempts have also been made to use the

inverse method, i.e., the cement treated is in motion while the liquid medium is at rest. The apparatus used by Guttman-Kohler[13] is of this type, and it is claimed that a complete separation of coarse from finer particles is obtained by repeated sedimentation. Such a process must necessarily be very laborious and slow, if separation into more than two fractions is required. Kühl[6] claims to have devised a sedimentation apparatus which will separate a cement into three fractions in 45 minutes. It consists of a long tube filled with alcohol and electrically heated by wire spirals wound on the outside of the sedimentation tube. The heating is so regulated that a temperature drop of 10 deg. C. is set up between the bottom of the tube and the highest heating element. By means of the uppermost spiral the top end of the tube is much more strongly heated, so that where this heater is located a temperature excess of 20 deg. C. is attained. This ensures thorough dispersion of the sample of cement for sedimentation in the top of the alcohol column. The coarser particles sink relatively quickly in the alcohol and fairly soon reach the bottom of the tube, while the finer grades sink more slowly. In order to collect and measure the various grades a side tube near the bottom of the column connects to a high reservoir of alcohol, the fine stream of liquid from which washes out into a filter paper the particles which have reached the bottom of the tube. A typical analysis by this apparatus is :

Per cent. by weight.	Grain size (in microns).
40.75	less than 16
8.23	16–23
13.38	23–33
23.97	33–57
11.29	57–100
2.38	greater than 100

The more detailed analysis of the fineness of a cement provided by the methods mentioned has been very useful in explaining differences in some cements which contain the same amount of flour. Heiser[7] pointed out that different methods of grinding the same clinker give cements of different setting times and strengths, although the sieve residue and flour content of each cement are the same.

It is well known that ball-milling gives a poorer quality cement than tube-milling, even when the cements are ground to the same percentage of flour. Also it is generally accepted that the usual grades of air-separated cements, although they may contain more flour than the ordinary tube-mill product when tested by the standard elutriator, yet do not give such good strengths. These differences are in the majority of cases explainable when the cement is further separated into finer fractions.

Hattori[8] examined microscopically the grit obtained from Portland cement after removal of the flour, and showed that it contained particles of irregular shape and varying from colourless to black in colour. Some grits are translucent and others opaque, while there are also particles of free silica and white, spherical,

free-lime particles. He concluded that the unsoundness of cement is due to the presence of such particles.

Meade[14] found that an unsound cement can be made to pass the boiling test by fine grinding and seasoning. A combination of these two processes probably allows the air to slake out the injurious ingredients. In this connection Schule and H. de Gottrau[9] found that with increasing fineness the loss on ignition increases and the specific gravity decreases.

Hauenschild[10] separated cements into fractions by a centrifugal-fan type elutriator, and from an examination of the fractions concluded that (*a*) the sulphate of the clinker and the added gypsum are mainly found in the finer fractions, (*b*) the loss on ignition is greatest in the finest fraction, (*c*) with the exception of (*a*) and (*b*) the fractions are very similar in analysis, (*d*) setting-time and volume-weight ratio decrease with increased fineness, (*e*) soundness increases with fineness, (*f*) the finest fractions (7μ and less) absorb CO_2 and H_2O very rapidly from the air and do not give the highest strengths, (*g*) the highest strengths are reached with grain sizes ranging from 19μ to 36μ.

In an examination of the fine flour particles Guttmann[15] in 1926 found that they contain a higher percentage of lime and gypsum than the larger particles. This has also been confirmed by Meade[14].

It is natural that the softer portions of a clinker should constitute the greater part of the flour in ordinary Portland cement, so that the hydraulically active portion of the cement will have a different composition according to the fineness to which it is ground. Meade[16] showed that the general influence of fine grinding is to make cement quick setting. This appears to be true particularly in the case of cements of high alumina and low lime content. He attributes this quickening of the set to the fact that as a cement is ground finer the harder particles are broken up, thus providing further compounds for interaction.

Petersen[11] showed that the quantity of water required for normal consistency increases with the degree of fineness, and the set is accelerated in like manner. He also showed that strength increases with fine grinding, the compressive strength showing a more notable and regular increase than the tensile tests. These facts are also supported by Helbig[12], who holds that only considerations of cost should limit the fineness to which cement is ground. In his experiments the strengths, at short dates especially, are much higher with increased fineness. The apparently conflicting results obtained by Kühl[17] and Hauenschild[10] are probably due to a combination of the following causes: (1) Laboratory ball-mill grinding not producing flour comparable in average grain size to that obtained in commercial tube-mill grinding; (2) no really fine product was obtained by Kühl, the finest cement obtained being about 1.8 per cent. on the 170-mesh sieve; (3) in the case of cements obtained by air separation, Helbig is of opinion that a partial set of the finest particles had taken place due to the moisture in the air during the separation, with consequent reduction in strength. Helbig's[12] work indicates that (1) strength falls as the sieve residue increases when grinding on

any particular mill, (2) strength falls as the mean grain size of the fine flour increases.

During recent years attention has been directed to the fictitious results given by tests on standard tensile test briquettes made from neat cement. Many years ago Meade[19] found that the strength of neat cement is lowered by finer grinding while the sand-mortar strength is increased. Inokuchi[18] in 1923 showed that the tensile strength of briquettes made from neat cement increases with the fineness of the cement to a maximum, beyond which it begins to decrease. With a Japanese cement the maximum was obtained when the cement was ground to leave a residue of 6 per cent. on the 170-mesh sieve.

The microstructure of hardened cement is composed of a large amount of unhydrated grains embedded in the hydrated mass. These grains are much harder than the ground mass and therefore, beyond a certain minimum of fines, the strength of the section of neat cement after setting is proportional to the percentage of unhydrated grains contained in it. This is one reason why the strength of neat cement briquettes made from very finely-ground cement is generally low. But fine cement has a high sand-carrying capacity, its mortar is dense, and the strength of the mortar briquettes is much higher. The fallacy of the strength test in neat cement has now been fully realised and no longer forms part of the British Standard Specification.

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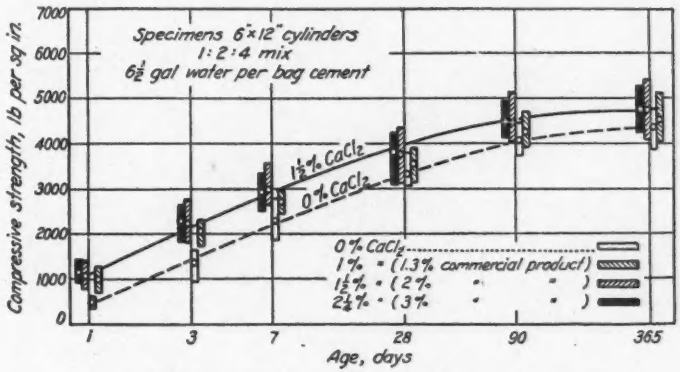
Heat of Dissociation of $CaCo_3$. (*Tonindustrie Zeitung*, 1935, p. 220).—According to Fellner and Ziegler, A.G., the latest figure for the heat of dissociation of calcium carbonate is 0.3795 kg. cal. per kg. $CaCO_3$.

Effect of Calcium Chloride on Portland Cements and Concretes.

DURING the past two years a fellowship had been maintained at the United States Bureau of Standards for studying the reaction of calcium chloride on Portland cement and its constituents. From measurements of temperature rise of a given amount of cement and water during the first 24 hours the quantity of heat evolved was calculated. The heat contributed by the individual compounds and the influence of calcium chloride on this heat were computed. The addition of calcium chloride appears to increase somewhat the heat contributed by dicalcium silicate and tetracalcium alumino-ferrite and to decrease the heat contributed by tricalcium aluminate. There is little change in the heat contributed by tri-



COMPRESSIVE STRENGTH OF EIGHT STANDARD PORTLAND CEMENTS, 1 : 2 : 4 CONCRETE.

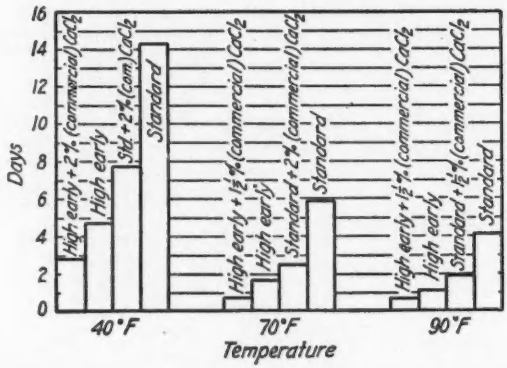
calcium silicate when calcium chloride is added. Calcium chloride increases the rate at which the heat is evolved by all cements tested. A study of a large number of experimental cements showed that the addition of calcium chloride increased the strength-contributing factors of the two calcium silicate compounds and decreased the strength-contributing factor of tricalcium aluminate. The effect of calcium chloride on the strength-contributing factor of tetracalcium alumino-ferrite is not readily apparent. The setting time of eleven commercial cements, together with the spread of the time of set of these cements, was decreased as the amount of calcium chloride was increased. With each cement the flow, as determined with a flow table, was increased by the addition of calcium chloride. Calcium chloride added to mortar and concrete not only greatly accelerated the early strengths, but appreciably increased the one-year strengths. These effects

were also produced by the addition of calcium chloride to 60 experimental cements. The optimum amounts to be added for different types of cement and at various curing temperatures are indicated in a report published by the Bureau.

The following conclusions have been drawn from the investigation:

(1) The heat contributed by the four major compounds of Portland cement during the first 24 hours was determined on neat cement pastes and also with the pastes to which 1 per cent. of anhydrous calcium chloride was added. Factors are given from which the heat evolved in 24 hours by a Portland cement may be computed from its compound composition, either with no calcium chloride or when 1 per cent. of anhydrous calcium chloride is present. The addition of calcium chloride increased the heat contributed by dicalcium silicate and tetracalcium alumino-ferrite, decreased the heat from tricalcium aluminate, and had little or no effect on the heat contributed by tricalcium silicate.

(2) The addition of calcium chloride increased the heat evolved by each of the cements tested up to 24 hours, even though that part of the total heat developed by the tricalcium aluminate was decreased. Although there was not



EFFECT OF CURING TEMPERATURE AND ADDITION OF CALCIUM CHLORIDE ON LENGTH OF TIME REQUIRED FOR CONCRETE TO ATTAIN 2,500 LB. PER SQUARE INCH STRENGTH (BASED ON PLASTIC MORTAR STRENGTH).

much change in the total heat evolved in 24 hours, the addition of calcium chloride markedly increased the rapidity with which this heat was evolved.

(3) Sixty experimental Portland cements were grouped according to the amount of heat evolved during the first 24 hours of hydration. It was found that for the group that developed only 30 to 40 calories per gram the addition of 1 per cent. of anhydrous calcium chloride increased the heat 7 calories per gram. Groups which evolve greater amounts of heat liberate less and less heat with the addition of calcium chloride, until in the group liberating from 70 to 80 calories per gram the addition of calcium chloride lowers the amount of heat liberated by 2 calories per gram.

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(4) The study (at 70 deg. F.) of the mortar strengths of 60 experimental Portland cements of widely varying composition at ages up to 28 days, beyond which no measurements were made, shows :—(*a*) Corroborating the findings of other investigators, the compound composition of Portland cement greatly influences its strength. The strength contributed by each of the four major components has been computed. (*b*) Calcium chloride increased the strengths of cement mortars, especially marked when the composition of the cement was within the range encountered in commercial Portland cements. (*c*) The addition of calcium chloride increased the strength contributed by dicalcium and tricalcium silicates. (*d*) The addition of calcium chloride increased the strength contributed by tricalcium aluminate for the first few days, but after this time decreased the strength contributed by this compound. (*e*) The contribution of tetracalcium alumino-ferrite to the strength is small. The addition of calcium chloride appears to make this factor slightly negative at all ages.

(5) The tests of 8 standard, 2 white and 1 high-early-strength commercial Portland cements, selected to obtain large variations in composition, show :—(*a*) The setting times of cement at 70 deg. F. were decreased by the addition of increasing amounts of calcium chloride. (*b*) The addition of calcium chloride increased the strength of each of the cements at all ages up to one year, beyond which tests were not made. Not only were the early strengths greatly increased by the addition of calcium chloride, but the one-year strengths were appreciably increased. Tests at 40 and 90 deg. F. also showed an increased strength at all ages up to 90 days, at which time the tests were terminated. (*c*) At 70 deg. F. the flow or workability of the concrete was increased by the addition of calcium chloride up to and including 3 per cent. of commercial calcium chloride. (*d*) Tests at 40, 70, and 90 deg. F. showed that the lower the initial curing temperatures the more effective is the use of calcium chloride as an admixture in increasing the early strength. (*e*) Integral use of calcium chloride was effective in accelerating the curing of all the cements. It is therefore of value in cold-weather construction in decreasing the time necessary for protecting the concrete.

(6) A tabulation is given showing the time required for normal Portland and high-early-strength Portland cements to attain a compressive strength of 2,500 lb. per sq. in. The effects of different curing temperatures, both with and without calcium chloride, are given. The optimum amount of calcium chloride which should be used at the three curing temperatures studied was found to be :—

Temperatures. Deg. F.	Commercial calcium chloride. per cent.	Type of cement.
40	2	All cements.
70	2	Normal and white.
	1.5	High early strength.
90	1.5	All cements.

Abstracts from the Foreign Press.

Wet Sieving for Works Control. By D. Steiner. (*Tonindustrie Zeitung*, 1935, p. 258).—Wet sieving gives results as good and often better than dry sieving for raw materials, coal, and cement. The chief advantages are that the material is not broken up and that the process is much quicker. In the case of cement the water has practically no effect on the comparatively coarse material which constitutes the residue. Drying is very rapid in a hot-air oven.

Law of Fineness Distribution in Cement. By G. Rothfuchs. (*Tonindustrie Zeitung*, 1935, p. 318).—Experiments by the author show that for maximum density in a powder the distribution of particles must follow the equation

$$p = \frac{\sqrt{d} - \sqrt{d_{min}}}{\sqrt{D} - \sqrt{d_{min}}} \times 100$$

where D = maximum diameter of particles in powder.
d_{min} = minimum diameter of particles in powder.
p = percentage weight of powder of particles smaller than d.
d = any particle size in the powder.

Four cements were examined and were found to follow this equation very closely. This shows that the particle size distribution in them was such as to give a maximum density when compacted.

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Action of Water on Tricalcium Silicate. By R. Nacken. (*Zement*, 1935, pp. 183, 214).—A large number of experiments in the system CaO-SiO_2-H_2O has been carried out in the light of the Phase Rule theory. It is shown that by the action of water on pure $3CaO.SiO_2$ a complete heterogeneous equilibrium is attained, or at least very closely attained. Compounds of the types $2CaO.SiO_2.xH_2O$, $3CaO.2SiO_2.xH_2O$, and $CaO.SiO_2.xH_2O$ can be demonstrated with certainty. Accurate estimation of the water content, however, was not possible in all cases. Probably the compounds are as follows: $2CaO.SiO_2.H_2O$ (Hillebrandite), $3CaO.2SiO_2.3H_2O$ (Afwillite), $CaO.SiO_2.2H_2O$ (Plombierite). Of these calcium hydrosilicates $2CaO.SiO_2.xH_2O$ and $3CaO.2SiO_2.xH_2O$ decompose on solution in water, while $CaO.SiO_2.xH_2O$ appears to be stable.

The late Mr. W. J. Coles.

We regret to learn of the death of Mr. Walter James Coles, a director of Edgar Allen & Co., Ltd., and manager of the engineering department of that firm. Early this century Mr. Coles went into partnership with Messrs. Maxted & Knott, the firm then becoming Maxted, Knott & Coles, its business comprising consulting work in connection with the erection of cement works, brickworks, etc. During this period Mr. Coles electrified the first cement works to be completely driven by electric power in this country at Haverton Hill. Eight years later Mr. Coles set up in practice in London as a consulting engineer in connection with cement plant, etc., and after eighteen months he joined Edgar Allen & Co. Ltd., as a technical consultant on cement plants. In 1914 he went to Sheffield and took over the management of the Engineering Department and in 1923 he was elected to the Board of Directors.

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